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Cost comparison of producing high-performance Li-ion batteries in the U.S. and in China

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HIGHLIGHTS

► We modeled the cost of Li-ion cells produced by hand and automated cell assembly.
► Volume cell production with automation equalizes cell cost worldwide.
► Materials costs constitute 80% of cell cost in automated production.

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ABSTRACT

This study compares the costs of manufacturing high-performance 18650-size lithium-ion cells in China and in the United States. The comparison reflects all costs of constructing and staffing a stand-alone manufacturing plant under current industry practice and using modern automated production techniques. Identical materials are used for each of the cells. This study finds that, when produced at large volume using automated equipment, cell materials account for 78–80% of total cell cost; costs for highly trained personnel are similar in China and the United States. Several other major drivers of production costs (such as logistics, land acquisition and energy costs) are higher in China, making total costs for each location roughly comparable. These comparisons suggest that U.S. manufacture of advanced batteries can be cost-competitive, and that Chinese battery manufacturing plants do not offer significant advantages in terms of profitability.

1. Introduction

For much of the 20th century, the United States led the world in manufacturing. Between 1980 and 2009, however, the United States lost 7.1 million manufacturing jobs, about 38 percent of its manufacturing base [1]. Today, the United States is ranked fourth in global manufacturing competitiveness, behind China, India and Korea, and further decline has been predicted as other nations develop increasingly strong manufacturing economies and offer lower-cost alternatives to U.S.-based manufacturing [2]. However, concerns about the future of U.S. manufacturing tend to focus on high-volume, commodity-oriented, low-skill, labor-intensive operations. Increasingly, modern manufacturing practices rely on highly automated production techniques that require a larger investment in infrastructure and a smaller number of skilled workers.

Advanced battery manufacturing represents a key segment of these newer, highly automated enterprises. The manufacture of lithium-ion battery cells requires extreme precision in assembly and a pristine manufacturing environment, making automation a necessity. The market for these cells is vast and growing; sales of 18650 lithium-ion battery cells – cylindrical cells 18 mm in diameter and 650 mm in length, and used for mobile computing and other consumer electronics applications – approached 10 billion units worldwide in 2010 [3]. At present, the vast majority of 18650 cells are manufactured in Asia, in highly automated factories that are similar in design and operation.

Because these highly automated processes require more highly skilled personnel, the substantially lower wages paid to unskilled workers in China are not a major competitive factor in the siting of these production plants. A comparison of the costs of battery cell production in the United States and in China indicates that highly automated production processes can make U.S.-based advanced battery manufacturing cost-competitive with Chinese production, and suggests that large-scale production of advanced batteries may be economically feasible in the United States.

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2. Early production of lithium-ion battery systems

As we have noted previously, U.S. researchers were at the leading edge of technological innovation in systems using advanced lithium-ion batteries when they were first commercially introduced in the early 1990s. The National Electronics Manufacturing Initiative (NEMI) roadmap studies quickly recognized advanced rechargeable batteries as a critical component in the growth of portable electronic devices [4].

Japanese battery makers moved swiftly to begin volume manufacturing of the new battery systems. Sony began lithium-ion battery production as a means to replace nickel–cadmium batteries in its portable consumer electronics, adapting production equipment used to make rechargeable nickel–cadmium batteries and modifying it to accommodate the properties of high-voltage, high-energy lithium-ion technology. Panasonic, Sanyo and Toshiba quickly followed in developing their own production capabilities.

The demand for higher performance prompted investment in R&D by private corporations as well as the Japanese government, which recognized the critical role that battery technology plays in portable electronics and vehicular transportation applications. The major Japanese manufacturers' investment in production capacity was significant throughout the 1990s, totaling billions of dollars, leading to steady improvement in production processes, along with new, higher-energy anode and cathode materials and new

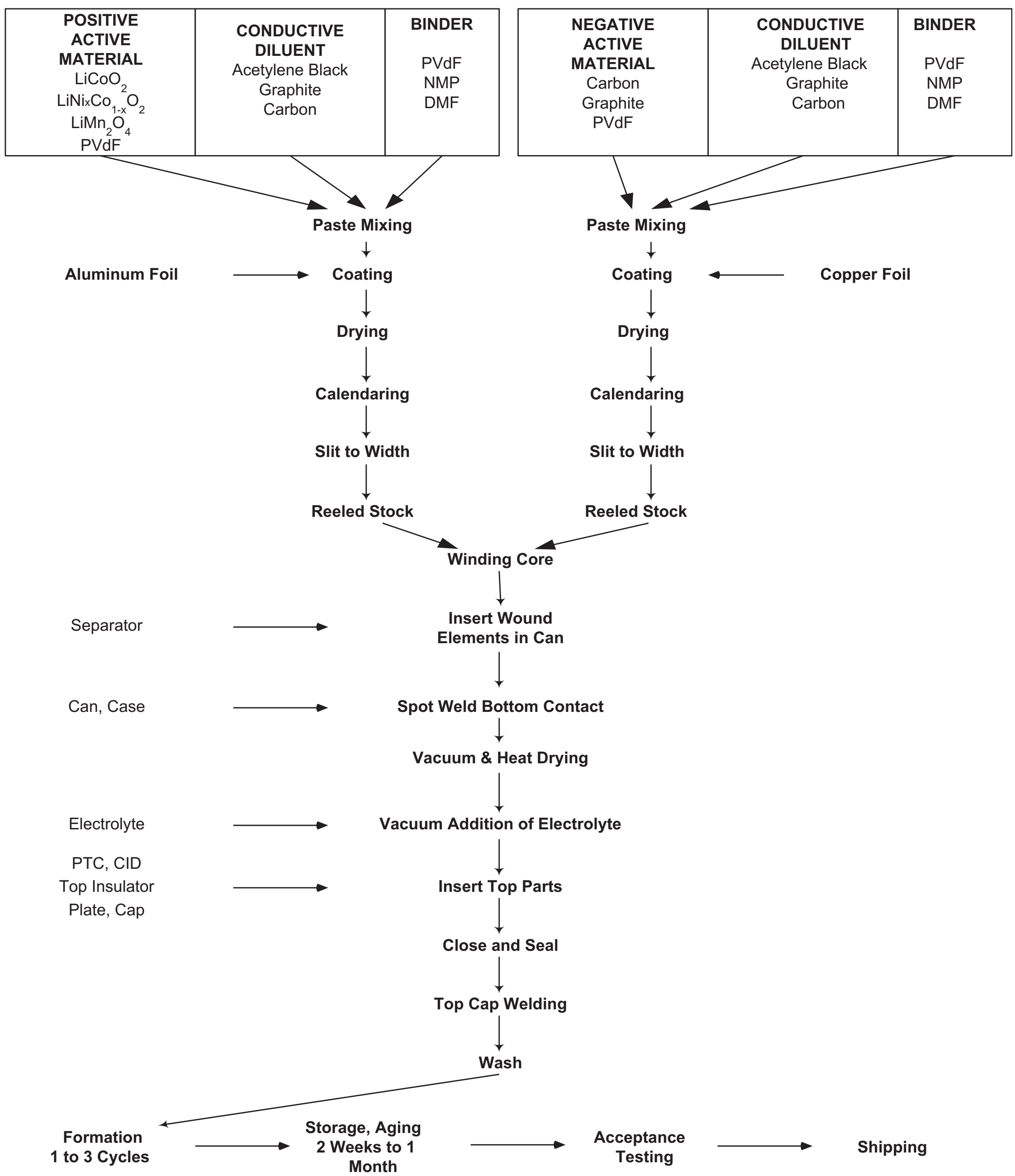

Fig. 1. Li-ion cell production process.

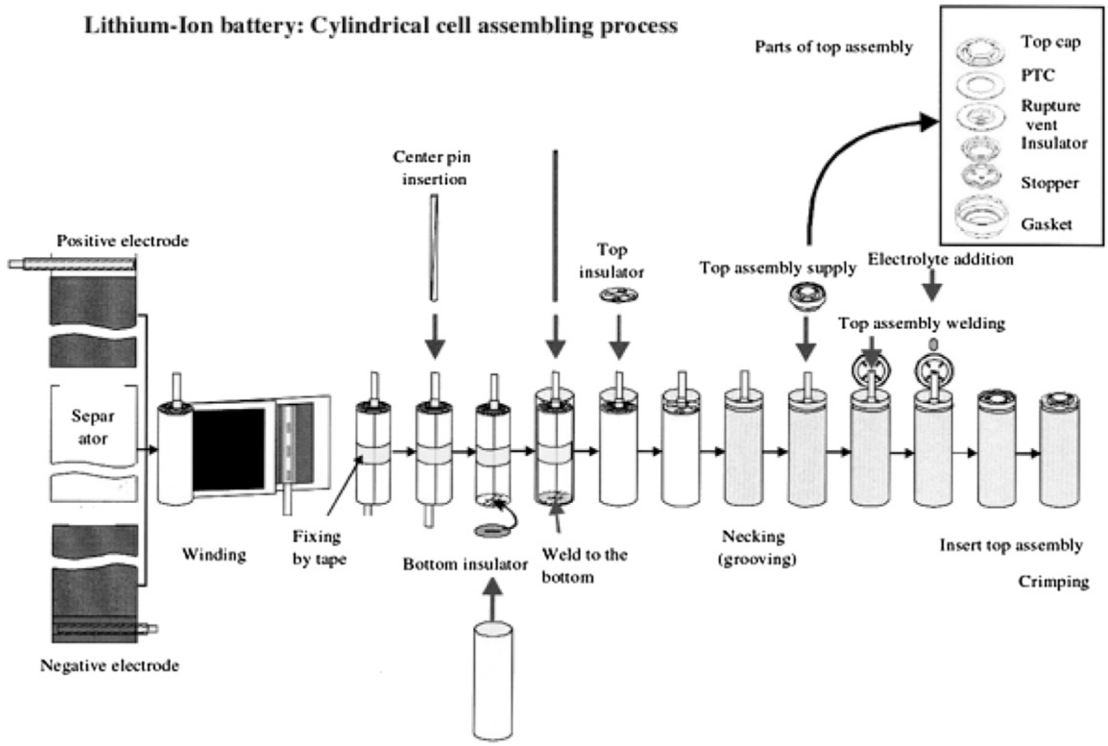

Fig. 2. Schematic for assembling 18650 Li-ion cells (courtesy of Hohsen Corp.).

electrolyte compositions [3] (see Figs. 1 and 2). These technological upgrades addressed increasing demand for batteries with longer operating time, to power portable electronic devices, such as cellular telephones and portable computers.

U.S. manufacturers were aware of the potential benefits of domestic lithium-ion battery manufacture but decided against attempting large-volume production, primarily because the new lithium-ion batteries offered a low return on investment compared with their existing business and required significant time and investment from conception to commercialization. Relative labor costs did not play a major role in impeding large-volume production of lithium-ion batteries in the United States, as skilled labor costs in Japan and the United State were essentially the same; more notably, U.S. manufacturers suffered competitively from the Japanese government's decision to provide facilities and low-cost loans to establish battery manufacturing plants [3]. Over time, however, the rapid expansion of lithium-ion battery manufacturing plants in Japan (and later, in Korea) created competitive difficulties for U.S. manufacturers of consumer electronics as well, as product development requires close contact between device designers and battery makers – relationships that are easily facilitated within the vertically integrated Asian companies [3].

Even as the United States continued to lead in the research and development of lithium-ion technology, Asian companies expanded their competitive advantage in commercialization and production of advanced batteries [5]. Seeing the long-term benefits of closer integration between battery manufacturing and consumer product design, some U.S. manufacturers did make attempts to establish domestic lithium-ion battery production. For example, in 1997, Energizer built a state-of-the-art lithium-ion battery manufacturing facility in Gainesville, Florida, with full production scheduled to begin by 2000. When the Gainesville Li-ion plant was in the "prove-in" stage, however, the world market price for lithium-ion cells abruptly declined, making domestic production less profitable than purchasing cells from Japanese manufacturers. The project was canceled and the factory was later sold [3].

3. The move to China

In the 1990s, small-scale production of lithium-ion batteries, using hand operations, began in China. Larger-scale production soon followed: Chinese and Taiwanese investors provided private funding for lithium-ion battery production at companies such as BYD, ATL, BAK, and B&K, which hired retired Japanese engineers and technologists to assist in developing battery production in support of the Chinese electronics industry. The Tianjin Power Sources Institute also played a critical role in developing Chinese battery production. The budding Chinese industry got a substantial boost when Motorola moved production of lithium-ion cells for its cellular phones from Japan to China's BYD.

Over time, China became a leader in production of lithium-ion batteries, reflecting the Chinese government's aggressive investments in advanced battery research and development and manufacturing facilities as well as large private investments; by 2008, there were more than 120 Chinese companies involved in the production of lithium-ion battery technology [5]. The Chinese industry has continued its initial strategy of drawing heavily on existing lithium-ion battery production techniques developed in other countries. For example, the Tianjin Lishen Battery Joint-Stock Co., Ltd., which has China's most automated production line for lithium-ion batteries, imported its production equipment from Japan [5]. As a result, Chinese factories use materials process flow and unit stations in their assembly lines that are very similar to their competitors in Japan and Korea, and produce cells that are equivalent in quality and performance. One significant difference should be noted: In Japan and Korea, cells are transferred automatically from one station to the next. In China, cells are often put into trays at each production station, examined visually or by x-ray

to assure quality control, and then are carried manually to the next station.

4. Current and future prospects for U.S. production of advanced lithium-ion batteries

Today, essentially all large-scale production of 18650 lithium-ion battery systems is based in Japan, China, Korea and other Asian countries. Although the United States imports an estimated 2 billion 18650 cells each year – nearly a third of the world's production – there are only a few small, specialty producers of the cells based here. Under the American Recovery and Reinvestment Act of 2009, the U.S. federal government invested $2.4 billion in electric battery production facilities, but these investments were focused solely on batteries for electric vehicle applications [6].

Over the past two decades, the conventional wisdom has held that high labor costs in the United States make it impossible for U.S.-based production of electronics and consumer goods to be cost-competitive with factories overseas, especially those in China. As manufacturing becomes increasingly automated, however, comparative labor costs play a lesser role in manufacturers' siting decisions. It should be noted, for example, that Japan – with higher labor costs than the United States – continues to be a leading producer of lithium-ion batteries, competing successfully with China and Korea. Japan's success in battery manufacture is attributable to high-speed, automated production and advanced quality control initiatives that minimize labor costs while producing high-performance products.

As the U.S. economy moves more strongly into recovery, it will be valuable to have a clear, precise, fact-based method to compare the costs of domestic manufacturing with the costs of outsourced production. This report addresses the need for reliable cost comparisons by presenting a detailed review of the various cost drivers of manufacturing 18650 cells in the United States and in China.

5. Methods

This report provides a detailed review of the various cost components of building and operating an automated lithium-ion cell production facility in China and in the United States. The 18650 cell was selected as the basis for comparison because it is the most widely sold lithium-ion battery, with sales volume approaching 10 billion cells in 2010. This report assumes that U.S. battery manufacturing facilities would use highly automated production equipment and processes identical to those in use today in China. (Details of the manufacturing process are provided below.) Cost considerations include initial capital investment as well as operating and materials costs, and include examination of the differing levels and types of government investment in building manufacturing facilities.

Table 1 sets out the basic cost drivers that must be considered in siting lithium-ion battery cell manufacturing facilities. This model considers variable and fixed costs, including the costs of skilled and unskilled labor, as well as capital spending and depreciation, interest expense, working capital requirements, plant overhead, administrative overhead, materials, and distribution cost. The author also has considered the additional costs of quality assurance oversight incurred by American companies using manufacturing facilities in China.

Table 1
Cost considerations in locating lithium-ion cell production facilities.

1. Land acquisition, facility construction and capital costs
2. Production, equipment and materials costs
3. Utilities
4. Logistics
5. Labor

The information in this study is derived primarily from the author's face-to-face interviews with selected individuals who hold research and management positions at battery manufacturing companies in China and in the United States, in addition to interviews with researchers at leading business schools. The author also visited battery manufacturing plants in China to assess the relative cost impacts of manual and automated cell production processes. Cost estimates for cell materials were provided by vendors. All costs are presented in dollars, using an exchange rate of 6 yuan = 1 dollar, a rate that reflects the gradually increasing strength of the yuan against the dollar.

5.1. Land acquisition, construction, equipment and capital costs

Although specific costs vary, the initial investment required to build a U.S. manufacturing facility for cylindrical 18650 lithium-ion cell production is roughly $4 per cell produced each year. This means that a U.S. facility capable of producing 30 million cells per year requires an upfront investment of about $120 million. The total upfront cost for a Chinese manufacturing facility is roughly $18 million less, for reasons noted below.

Land costs are significantly higher in China, where leasing is more common than outright purchase. A recent report by the Boston Consulting Group noted that the average land cost in China is $110 per square meter, but actual costs vary dramatically; for example, industrial land costs $155.97 in Nanjing, $186.11 in Shanghai, and $226.04 in Shenzhen. Land costs are significantly lower in much of the United States, ranging from $20.02 to $79.98 per square meter in Alabama, and from $13.99 to $50.05 per square meter in Tennessee and North Carolina. Although manufacturers can find significantly less expensive manufacturing sites in inland China, the savings in real estate costs must be weighed against higher transportation costs and more limited infrastructure [7].

The substantially higher costs for Chinese land acquisition are offset by lower construction costs: an average of $805 per square meter of internal area in China in 2010, compared with $1700 per square meter in the United States [8]. For a U.S. facility with an annual production capacity of 35 million units, construction would cost $54 million; in China, construction would cost $33 million. This difference reflects both lower Chinese labor costs and variations in local construction practices; Chinese construction companies often use low-cost, energy-inefficient materials because buildings in China tend to change hands frequently, making long-term paybacks from electricity savings irrelevant to the initial building owner [9]. The differential in construction costs is reflected in facility depreciation, which is lower in China by a factor of 1.6. Interest rates for construction loans are identical in China and the United States.

Equipment costs, and therefore equipment depreciation, are currently identical in China and in the United States, as they import most production equipment from the same sources in Japan. Although China is developing the ability to fully engineer and supply equipment needs internally, this report assumes that manufacturers in both countries will import the same equipment using the same suppliers.

Another factor that is difficult to assess is the relative cost of liability coverage in China and the United States. The Chinese companies surveyed do not carry commercial liability insurance and instead self-insure, meaning they are financially responsible for any successful liability claims. In the United States, most manufacturers choose to carry commercial liability insurance. As a result, the relative insurance costs noted below are somewhat

lopsided. However, it should be noted that the financial impact of a large liability claim on an individual Chinese manufacturer could potentially be substantial, raising the unit cost of cells produced.

5.2. Production processes and materials costs

The energy conversion market is driven by the demand for low-cost, high-performance, defect-free cells, a demand best met by highly automated production. Typical automated assembly processes are shown in Figs. 1 and 2. (The processes shown do not include any proprietary processing steps or quality control inspections.)

In highly automated facilities in Japan and Korea, cell assembly is completed in one continuous operation. The roll of coated electrode stock is fed into the assembly line, and all intermediate steps in the process are automatic and connected by a traveler. Vision systems check the quality of each operation, sometimes supplemented by special techniques such as using impedance to check for internal shorts after winding or component placement. As mentioned earlier, Chinese facilities significantly lack automated transfer between assembly stations; instead, each station in cell assembly is separate. After each process, cells are placed in a tray, manually moved to an examination station away from the production floor and inspected for defects, both visually and by x-ray. Employees cluster around each examination station, making it difficult to estimate the number of people actually involved in each operation. Cells with defects are removed from further processing; the remainder are then carried back to the next assembly station. Despite this more time-consuming process, production rates are essentially the same for factories in Japan and China. Materials costs in the United States and China are identical, as shown in Table 2.

5.3. Utilities costs

Manufacturers in China face rising utility costs and increasingly uncertain supply, with demand trending steadily upwards. In November 2011, China's National Development and Reform Commission on Wednesday raised national retail electricity prices for nonresidential users by 5%, with regional prices per kWh ranging for 12–18 cents [10]. By contrast, U.S. industrial users pay an average price of 6.5 cents per kWh [11]. Energy consumption in advanced battery manufacturing plants is a relatively minor contribution to the cell unit cost. Current estimates put battery assembly energy usage between 3 and 9 kWh_{used}/kWh_{cell} [12]. For a facility producing 350 million cells, production in China would have approximately $1.5 million higher electricity costs.

Since 2010, China has been the world's largest consumer of energy [13]. In 2011, energy consumption in China increased by 7%, the highest rate of increase in four years [13]. The vast majority – about 70% – of China's electricity is produced by coal, resulting in levels of air pollution that have imposed significant economic costs [14]. China also is the second-largest net oil importer in the world, behind the United States, with net oil imports reaching about 4.8 million barrels per day in 2010 and an increase of 1.1 million barrels per day projected by the end of 2012 [15]. The China Electricity Council predicted a power supply gap of 30–40 GW for the 2012 summer season, reflecting a combination of high temperatures, falling hydropower output and coal shortages.

Table 2
Bill of materials per cell.

Component	Cost ($)
Cathode active material (NMC)	0.52
Separator	0.14
Electrolyte	0.13
Anode active material (graphite)	0.16
Can, headers and terminals	0.17
Copper foil	0.06
Other (including scrap)	0.12
Total materials cost per cell	1.30

5.4. Logistics costs

China's high energy prices contribute to increased logistics costs, and fragmentation in the logistics industry has created notoriously challenging supply chains within the country. In the words of one European whose company manufactures in China, "Supply chain is intellectual property" [16]. KPMG reports that the estimated total number of transport and logistics companies operating in China ranges from 60,000 to 700,000 [17]. In 2011, the American Trucking Associations reported that moving goods by truck in the United States costs about $1.75 per mile, a figure that includes driver salaries, truck leases, insurance, tolls and other related costs. Trucking costs in China's two biggest export regions — the Yangtze River Delta region near Shanghai and the Pearl River Delta around Hong Kong — range from $2.50 to $3 a mile, despite much lower wages for Chinese drivers [18]. The higher costs reflect local and provincial road tolls and fees, which can account for 30–40% of trucking companies' transport costs [17]. These logistics costs do not include the freight and customs costs of shipping products from China to the United States, which adds about 4.5% to the unit price of 18650 cells. These costs have increased sharply over the past decade; the shipping cost of a fully loaded standard 40-foot container from China to the United States rose from about $3000 in 2002 to about $6000 in 2011 [19].

These costs do not include the highly variable but often significant costs of sending U.S. executives to China for lengthy visits to manufacturing facilities, the challenges of communicating across language barriers and time zones, or the complexities of quality control, which can be magnified by the delays caused by trans-Pacific shipping.

5.5. Labor costs

As mentioned earlier, the substantially lower prevailing wages in China have been cited frequently as an insuperable barrier to any possibility of U.S. competitiveness in manufacturing. However, it is misleading to focus solely on a side-by-side comparison of average wages in the United States and China. As previously noted, advanced battery factories are highly automated, and many factory employees are highly skilled workers who earn salaries far higher than the national average.

There are certainly non-negligible differences between wage expense for U.S. and Chinese battery manufacturing plants; total labor cost in China for a fully automated plant with a capacity of 350 million cells per year represents only 3% of product cost, compared with 12.5% of total cost in the United States. However, much of that difference is offset by Chinese plants' higher costs for energy and transportation; Chinese wages and benefits have been rising noticeably over the past few years, reducing the Chinese cost advantage even further [20].

As is well known, labor practices in China are very different from those in the United States. Chinese manufacturers recruit semi-skilled workers from all parts of China, offering wage and benefit packages that total between $2.42 and $3.63 per hour. A typical Chinese battery manufacturing facility consists of the main cell assembly plant and dormitories and cafeterias for hourly production workers. There are separate dormitories for singles and married couples with families. These manufacturing facilities can

be the size of small towns; up to 5000 workers may be required for a non-automated factory producing 20 million cells annually.

Chinese benefit packages include room and board, transportation to and from the factory, medical coverage, and seven paid national holidays. Workers also are legally entitled to 5–15 days of paid vacation each year, although many Chinese workers report that they do not take any paid vacation time [21]. In total, benefits in China comprise about 25% of salary, compared with 27% in the United States.

Any comparison of Chinese and U.S. wages should note that average salaries for scientists, engineers and upper management personnel in China equal or exceed those of their counterparts in the United States, as detailed in Table 3. Additionally, senior Chinese management personnel often are provided with chauffeured cars and living quarters.

A recent study by the Boston Consulting Group highlights the steady rate of increase in Chinese average wages. From 1999 through 2006, for example, the average Chinese wage increased by 150%, and from 2005 to 2010, the average Chinese wage increased by 19 percent *annually*. Looking ahead BCG projects that the fully loaded cost of compensation packages for Chinese workers in the Yangtze River Delta will increase by 18% each year, to about $6.31 per hour. This trend may accelerate, given recent internal and external pressures on Chinese manufacturers to increase wages and improve working conditions [22].

Several other factors must be considered in assessing relative labor costs in China and the United States. For example, Chinese productivity rates, while rising significantly, still lag far behind the United States; although head-to-head average wage comparisons dramatically favor China, adjusting wage rates to reflect China's lower output per worker significantly reduces the Chinese cost advantage – a trend that is likely to continue, the BCG report concludes [20].

Related to labor costs is the question of matching worker skills to employer needs in a specific geographic location. Although China's labor assets are enormous, average skill levels are typically lower than in the United States. As a result, Chinese manufacturing plants – even those that are highly automated – tend to have higher rates of defective products.

5.6. Total relative production costs in the United States and China

Table 4 shows the impacts of these relative differences in production costs on the total cost of each cell. Because labor costs are higher in the United States, cell components make up a smaller proportion of the total unit cost. Insurance costs also are substantially higher in the United States due to differing business practices, as discussed above.

6. Modeling manufacturing cost structure

Given the relative costs detailed above, the author developed a model to answer the fundamental question: At current costs, does China continue to offer U.S. manufacturers a cost advantage in the manufacture of 18650 lithium-ion battery cells?

To answer this fundamental question, and to establish a cost comparison between the two countries, the authors have constructed a model featuring several different manufacturing scenarios. These scenarios assume similar standards for product quality, employee safety, environmental protection and business ethics in China and the United States.

The variables in the first models include:

6.1. Plant capacity and type

To better quantify the impact of economies of scale, the author considered two sizes for plants producing the 18650 lithium-ion cell: a smaller plant that produces 35 million cells a year, and a larger facility that produces 350 million cells a year. The models also compare both manual and semi-automated Chinese plants with automated U.S. plants.

6.2. Compliance with U.S. office standards

When producing in China, a U.S. company can choose to operate its facility in compliance with U.S. manufacturing standards and in close communication with U.S. personnel, or it can create a stand-alone plant with extremely limited interactions with U.S. operations. These stand-alone plants require no executive travel from the United States to China, no transfer of technology or engineering, no training of Chinese personnel to comply with specific processes used in the United States, and no effort to create compatible quality and information systems across U.S. and Chinese facilities.

The manufacturing parameters assumed for the plants are set out in Table 5, with the figures for the larger plant included in parentheses.

Table 6 sets out the total production cost per cell manufactured at a U.S.-based facility vs. the costs per cell manufactured at a stand-alone plant in China. The chart includes production costs for a non-automated plant in China only, as such plants do not exist in the United States.

Table 3
Comparative average hourly labor costs in the United States and China.

	U.S. ($)	China ($)
Unskilled direct labor	15.24	2.42
Skilled direct labor	24.66	3.63
Building maintenance	17.78	4.84
Equipment maintenance	27.94	27.94
Administrative support	22.86	9.69
QA/purchasing support	25.40	9.69
Management	54.00	36.34
Supervision	42.00	9.69
Lab/Scientist	34.80	14.53
Engineering	40.80	14.53
Plant manager	96.00	96.00

Table 4
Production cost components.

	35M process		350M process	
	U.S. (%)	China (%)	U.S. (%)	China (%)
Cell components	73.63	81.38	79.00	82.18
Total labor	13.57	7.71	12.93	6.95
Utilities	1.31	2.91	1.81	3.78
Land and building (39 years depreciation)	0.23	0.12	0.24	0.16
Capital equipment (15 years depreciation)	2.10	1.33	2.18	1.20
Financial	2.86	1.97	2.97	1.94
Insurance	6.30	0.70	0.87	0.09
Freight and customs	0.00	3.90	0.00	3.71
	100.00	100.00	100.00	100.00

Table 5
Assumptions for manufacturing parameters.

Number of cells produced/yr	34,992,000 (349,920,000)
Numbers of lines	1 (10)
Winder speed	30 cells/min
Number of winders per line	3
Time per shift	400 min (about 20 min are lost at the start and finish of each shift)
Number of shifts/day	3
Production days per year	360 days
Yield assumed	90%

Table 6
U.S.-based manufacturing facility vs. stand-alone plant in China.

Plant capacity	35M			350M		
	U.S.	China	Δ (U.S. − China)	U.S.	China	Δ (U.S. − China)
Process automated	$2.1882	$1.8801	$0.3081	$1.6466	$1.5756	$0.0710
Process manual	NA	$1.9722	NA	NA	$1.5827	NA

Table 7
Plant in compliance with home office manufacturing standards.

Plant capacity (annual)	35M			350M		
	U.S.	China	Δ (U.S. − China)	U.S.	China	Δ (U.S. − China)
Process automated	$2.1882	$1.9205	$0.2677	$1.6466	$1.5808	$0.0658
Process manual	NA	$1.9927	NA	NA	$1.5881	NA

Table 7 details the total production cost per cell manufactured at a U.S.-based facility vs. the cost per cell manufactured in a Chinese plant that is fully compliant with U.S. processes and standards.

7. Discussion

For any battery manufacturer, the most significant costs are the upfront expenses of facility construction and equipment purchase and the costs of cell components. These costs are roughly equivalent for manufacturers in any nation. In previous years, decisions on placing of the plant site were deeply influenced by the substantially lower prevailing wages in China. However, the increasing automation of battery manufacture, combined with the steadily increasing wages of highly skilled Chinese workers, raises the important question of whether, in fact, advanced battery factories in China offer significant cost savings over those sited in the United States.

As the tables in the previous section make clear, even highly automated smaller factories in China can produce batteries at a lower cost than facilities of a similar size in the United States. A Chinese plant manufacturing 35 million cells a year can offer a unit cost that is nearly 25 cents lower than a U.S. competitor. For a plant of this size, China remains the most cost-effective site at the present time. However, the gap in costs between China and the United States narrows to about 7 cents per unit for plants producing 350 million cells per year. This difference decreases slightly when comparing U.S.-produced cells with those made in Chinese plants that comply with U.S. operating practices.

We would argue that this cost differential is not significant enough to influence a siting decision, especially given the number of potential drivers of cost increases in China, including – but not limited to:

a) Fluctuations in exchange rates that will strengthen the yuan against the dollar, driving up overall product costs.
b) Increases in prevailing Chinese wage rates, reducing the differential in labor costs relative to the United States.
c) Limited availability of highly skilled labor, especially at the supervisory and management levels, providing upward pressure on wages of higher-level employees.
d) Disparities in quality between cells manufactured in highly automated facilities and cells manufactured using manual processes in China, a disparity that may be the relatively lower skill levels of Chinese workers.
e) Unexpected supply chain disruptions, which drive a need for increased domestic inventories and related cost increases.

This study does not attempt to quantify less tangible benefits that U.S. companies may experience by locating manufacturing facilities domestically, such as innovative synergies that may develop when R&D personnel have convenient access to the factory floor. It also is difficult to place a specific value on U.S. consumers' preference for U.S.-made products; what cost premium would consumers be willing to absorb to "Buy American"?

Certainly, each battery manufacturer ultimately must make its own calculations about the relative costs and benefits of a specific potential facility site. However, it is extremely important, both for the individual manufacturer and for the U.S. economy as a whole, that these siting decisions be based on updated, thoroughly researched, industry-specific information. The authors believe that, looking toward the future, U.S. manufacturers will find it increasingly attractive and profitable to build highly automated advance battery manufacturing facilities in the United States, nearer their R&D facilities and closer to their ultimate consumers.

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